Research Vessel Surveys

USA research vessel sea scallop surveys have been conducted since 1960 to obtain fishery independent data on the ecology and abundance of the Georges Bank and Mid-Atlantic scallop populations (Serchuk et al. 1979). These surveys form two time series: an early series conducted during 1960-1968 primarily in the Georges Bank region in which collection of basic life history information was a principal survey objective although relative abundance and population structure were also derived (Merrill and Posgay 1964; Haynes 1966; Posgay 1979), and a newer series conducted in 1975 and annually from 1977 onward to specifically monitor population dynamics of the Georges Bank and Mid-Atlantic resources (Table 27).

Since 1979, USA surveys have been performed using the R/V Albatross IV equipped with a 2.44 m (8 ft) wide commercial sea scallop dredge possessing a 5.1 cm (2-inch) ring bag and a 3.8 cm (1.5 inch) polypropylene mesh liner. Detailed gear specifications are given in Serchuk and Smolowitz (1980). At each sampling station, the survey gear is towed for 15 minutes at 3.5 knots with a 3:1 wire scope. A stratified random sampling design is employed, with offshore areas between 27-110 m (15-60 fathoms) stratified into geographical zones based on depth and latitude (Figure 18). Sampling stations are allotted to strata in proportion to the area of each stratum and assigned randomly within strata. The current sampling strata encompass the main areal and bathymetric distribution of sea scallop populations on the Northwest Atlantic continental shelf.

USA scallop surveys accomplished between 1975 and 1978 used a 3.05 m (10 ft) wide, unlined scallop dredge as the standard sampling gear. Alternate haul comparative fishing selection experiments conducted in 1980 with lined and unlined 2.44 m (8 ft) sea scallop survey dredges (Serchuk and Smolowitz 1980) revealed significant differences in size selectivity between the lined and unlined gear;

for scallops <70 mm shell height, the lined dredge was much more efficient in capturing individuals than the unlined dredge while for scallops ≥70 mm the obverse was true (Figure 19). Equally, relative retention efficiency for the lined dredge progressively decreased with increases in scallop shell size between 25 and 70 mm. Accordingly, to standardize the 1975-1978 USA sea scallop survey results with subsequent survey data, individual tow catches were adjusted, by shell height size category, to reflect the size selectivity of the currently employed lined dredge. Also, a linear adjustment factor was applied to the earlier survey tow data to standardize the 3.05 m dredge results to 2.44 m dredge equivalents (0.8 = 2.44/3.05). Overall selectivity and gear adjustment factors used in the standardization process are presented, by shell height interval, in Table 28.

Although a stratified random sampling design was used in the 1977 and 1978 USA scallop surveys (the 1975 survey used a transect design), sampling strata differed from those used since 1979. To facilitate comparisons with more recent survey data, standardized tow data from the 1975-1978 surveys were post-stratified, before further analysis, into the current USA strata regimen.

Since 1977, Canada has conducted annual sea scallop research vessel surveys on Georges Bank, primarily in the Northern Edge and Peak region. These surveys are performed with the R/V E.E. Prince using a 2.44 m (8 ft.) offshore scallop dredge equipped with 7.62 cm rings (3-inch) and a 3.81 cm (1.5 inch) mesh nylon liner (Jamieson and Chandler, 1980). Sampling areas are selected on the basis of commercial effort expended by the combined USA and Canadian scallop fleets within 10-minute squares of latitude and longitude. Sampling stations are allocated to 10-minute square areas in proportion to the relative amount of commercial effort and CPUE in each square; within squares, stations are randomly located (Jamieson 1977). Sampling intensity is facilitated by characterizing 10-minute square areas into low, medium, and high commercial catch per effort categories. A standard tow at each sampling station linearly covers 0.8 km (0.5 n mi) of ocean bottom as determined from LORAN navigational bearings (Jamieson and Chandler 1980).

Canadian survey data from the Northern Edge and Peak region were integrated with USA survey results by post-stratifying individual tow data into the USA sampling strata. The Canadian survey data were further adjusted to account for differences in the mean tow distance between USA and Canadian standard sampling tows. The mean tow distance per station on Georges Bank during the 1978-1981 USA surveys was 0.89 nautical miles in 1978, and 0.87 nautical miles in each of the succeeding three years. Hence, Canadian survey catch data were expanded by the ratio of the mean USA survey tow distance to the mean Canadian survey tow distance, i.e., 1.78 in 1978 and 1.75 for the 1979-1981 surveys. No selectivity adjustments were performed to the Canadian survey data since the Canadian survey dredge is almost identical to the USA 2.44 m lined survey dredge in configuration.

In both the USA and Canadian sea scallop surveys, similar catch processing procedures are employed. After each tow, the catch is sorted into biological and trash components. The entire scallop catch is weighed and shell height frequency measurements by 5 mm intervals, recorded for all individuals. On occasion, subsampling is necessary if extremely large quantities of scallops are obtained. Following enumeration of total number and weight of scallops caught, biological samples (shells, meat weights, ovary weights, etc.) are collected for aging, maturity, relative fecundity, and height-weight analyses. Frequently, samples are also obtained for special analyses (i.e., heavy metals, glycogen levels). Hydrographic and navigational data are routinely recorded at each sampling station including tow distance over bottom using a Doppler speed log.

A summary of USA and Canadian sea scallop survey cruises on Georges Bank and in the Mid-Atlantic from which data have been analyzed in this report is provided in Table 27. Data from USA surveys prior to 1975 were previously presented in Serchuk et al. (1979).

Survey monitoring of offshore Gulf of Maine sea scallop populations has been conducted as part of the USA annual spring and autumn bottom trawl surveys in this geographical region. Although the USA standard bottom trawl gear is not as efficient in sampling scallops as the sea scallop survey dredge (due to rollers on the trawl sweep), a preliminary comparison of relative abundance and size frequency data derived from USA trawl and dredge surveys on Georges Bank revealed similar historical trends. Accordingly, the use of bottom trawl surveys to obtain data on abundance and size structure of Gulf of Maine scallops appeared justified. Methodology and design of the stratified random bottom trawl surveys are detailed in Grosslein (1969, 1974), Pennington and Grosslein (1978) and Clark (1979, 1981).

Gulf of Maine bottom trawl sampling in strata 26-30 and 36-40 (Figure 20) during 1963-1981 resulted in the regular collection of scallops in strata 26-27 and 37-40. Tows performed in strata 28-30 and in stratum 36 yielded a total of only 26 scallops from all spring and autumn surveys. Hence, these strata were eliminated from subsequent analyses. The remaining Gulf of Maine strata were grouped, for analytical purposes, into two depth categories: 31-60 fm (strata 26, 39 and 40) and 61-100 fm (27, 37 and 38). Prefatory inspection of scallop data from these two depth zones revealed significant differences in population composition and abundance.

Due to uncertainty concerning the consistency of recording scallop catch data during Gulf of Maine bottom trawl surveys prior to 1974, only 1974-1981 survey data were analyzed for assessment evaluations. Cruise tracks and operational summaries of these surveys are provided in Patanjo (1979, 1981) and Azarovitz (1981).

Research Survey Relative Abundance Indices

Sea scallop research survey relative abundance indices were calculated in terms of standardized stratified mean catch per tow in numbers following the procedures of Cochran (1977: p. 91) and Pennington and Grosslein (1978). In all years, survey indices were tabulated for pre-recruit size scallops (<70 mm shell height, recruited scallops (≥70 mm shell height), and total scallops (all sizes) per tow. Linear total catch per tow values were also transformed to logarithms (ℓn x+1) and retransformed estimates of total relative abundance calculated (Bliss 1967: p. 128) to normalize the distributional properties of the survey data and stabilize variances. Size-related parameters (mean shell height, mean meat weight per scallop sampled, and average meat count) were also derived from stratified survey height frequency distributions in all years for each area sampled (Figures 21-30).

On Georges Bank, trends in survey indices during 1975-1981 differed among the principal sea scallop regions(Table 29). In the South Channel region, the total linear number per tow index was relatively high in 1975, declined by about 50% by 1978, increased to a peak in 1980, and declined in 1981 to the lowest level in the recent South Channel time series. Pre-recruit indices in the South Channel were high in 1975 (30.2) and 1980 (51.2) implying above-average recruitment; size frequency modes in these years indicate that the 1972 and 1977 year classes were relatively successful ones (Figure 22). The 1981 pre-recruit value, however, suggests that recruitment of the 1978 year class into the commercial fishery during 1982 will be relatively minor.

Declines in the South Channel recruited scallop indices (1977-1978: 52.5 to 33.9; 1979-1981: 56.5 to 24.0) were associated with increased landings levels. Between 1975 and 1977, annual South Channel landings increased almost fourfold (Table 5); total landings in 1977 (4,382 tons) were the highest on record. Subsequent annual South Channel catches have remained at historically high levels, averaging 3,300 tons during 1978-1981, greater than twice the 1957-1975 mean annual catch. The increased dependence of the fishery in recent years upon incoming recruitment (Table 19) and the concomitant rapid reductions in survey indices of commercial-sized scallops immediately after recruitment imply that recent South Channel exploitation rates have been extremely high. The exceptional 1955 year class sustained above average South Channel landings throughout 1959-1964; the two most recently successful year classes (1972 and 1977) together have sustained only 63% more yield during the 1976-1981 five year period than the 1955 year class did in a six year interval. Since commercial CPUE indices declined by about 50% during 1978-1980 (Table 14), the implication is that the recent annual landings reflect increased fishing mortality on year classes less abundant than the 1955 cohort.

Survey abundance indices in the Southeast Part of Georges Bank during 1975-1981 have fluctuated in nearly the same fashion as South Channel values except no survey evidence exists suggesting significant recruitment of the 1972 year class in this region (Table 29; Figure 23). Total number and recruit number per tow indices declined between 1975-1979, increased in 1980, and then fell to their lowest levels in 1981. Pre-recruit indices in 1979 and 1980 were higher than former values; Southeast Part survey size frequency distributions for these years (Figure 23) display modes at 40-50 mm and 80-90 mm indicative of good recruitment from the 1976 and 1977 year classes. The sharp reduction in all of the 1981 indices connotes, however, that neither these year classes nor the 1978 year class are presently highly abundant. Annual Southeast Part landings doubled between 1976 and 1977 and almost tripled between 1977 and 1979 (Table 5). Yearly landings since 1977 have been higher than any since 1965. As in the South Channel, these heightened landings levels have been accompanied by marked declines in the abundance of scallops in the Southeast Part area.

Survey catch per tow indices for the Northern Edge and Peak area have consistently been higher than those from any other region on Georges Bank or in the Mid-Atlantic (Table 29). Nonetheless, the recent series of survey values have exhibited the same general magnitude of fluctuation as in other regions. Total numbers per tow on the Northern Edge nearly tripled between 1975 and 1978, declined by 46% in 1979, and doubled in 1980. In 1981, total catch per tow was slightly less than in 1980 (681.9 vs 727.5). All of the 1981 Northern Edge and Peak catch indices, however, are believed to overestimate relative abundance compared with former years (perhaps by as much as 50%) since only half of the 10 strata comprising the standard Northern Edge and Peak strata set were sampled in the 1981 Canadian scallop survey. Because the five strata sampled in 1981 (Strata 63-66 and 71: Figure 18) have historically yielded the highest catch per tow indices of any in the Northern Edge strata set, stratified abundance estimates from the 1981 sampling over-represent regional scallop densities relative to previous surveys in which all of the Northern Edge and Peak strata were normally sampled. This can be substantiated by comparing the 1980 and 1981 stratified mean number per tow indices derived from the five strata sampled in 1981. A 54% decline in relative abundance (1492.5 vs 681.9) is evident between years.

Pre-recruit indices from the Northern Edge surveys in 1978, 1980, and 1981 suggest above average abundance of the 1975 and 1978 year classes and exceptional year class strength for the 1977 year class (Table 29). Prior to 1979, the 1972 year class dominated the Northern Edge and Peak scallop resource as evinced by annual modal progressions in the survey size-frequency distributions during 1975-1978 (Figure 24). The appearance of successful year classes on the Northern Edge and Peak is also reflected in reductions in mean shell height and meat weight, and increases in average meat count in the annual survey samples (Table 29).

The shell height frequency distributions from the Northern Edge and Peak region clearly indicate that the survey gear tends to effectively capture pre-recruit scallops after individuals have attained a size of 30 mm shell height, corresponding to scallops in their third year of life (i.e., older than age 2) (Figure 24; Table 20).

Occasionally, as in the South Channel in 1981, age 2 scallops (20-30 mm shell height) have appeared in survey catches (Figure 22). Hence, incoming recruitment to the commercial fishery can usually be assessed from survey data at least one to two years beforehand. This is corroborated, for above average year classes, by the appearance of prominent commercial size frequency modes between 70-90 mm and 90-110 mm one and two years after a cohort is identified in the survey frequency distributions by a mode between 30 and 60 mm. Equally, significant declines in the mean size of scallops sampled in the surveys are normally followed, a year later, by significant declines in the mean size of scallops in commercial samples (Tables 17 and 29). Both of these conditions prevailed in the 1981 Northern Edge and Peak commercial fishery which focused upon recruitment from the 1977 year class, detected as an outstanding cohort in the 1980 survey.

In response to recent improvements in recruitment, landings from the Northern Edge and Peak region have been at record and near-record levels. Total yearly landings during 1977-1981 averaged nearly 11,200 tons, 77% greater than the 1957-1976 mean, and 2,340 tons higher than the average annual landings that occurred during 1959-1964 when the exceptional 1955 year class sustained the fishery (Table 5). The relative dearth of scallops larger than 100 mm in the 1981 survey size frequency distribution (Figure 24) and the concomitant increase in commercial meat counts during 1981 (Table 19), however, suggests that incoming recruitment, upon fishery entry, has been rapidly harvested. It is likely that a similar situation will pertain in the 1982 fishery as the 1978 year class becomes recruited.

In the Mid-Atlantic area, survey relative abundance indices for all major regions were markedly lower in 1981 than in almost all previous survey years (Table 30). All regions exhibited relatively high catch per tow values in 1975 due to widespread success of the 1972 year class (Figures 25-28: 60 mm mode). Subsequent recruitment, however, has generally been much poorer. In the New York Bight, pre-recruit indices were extremely low during 1977-1979 although the 1980 and 1981 values indicate moderate recruitment from the 1977 and 1978 year classes (Table 30; Figure 26). The latter two indices, however, are still less than half of the 1975 pre-recruit value. In Delmarva, localized recruitment was apparent from the 1979 and 1980 pre-recruit catch per tow indices (30.8 and 23.4, respectively) implying above average year class strength for the 1976 and 1977 cohorts. These year classes, however, subsequently appeared of minor significance in the 1980 and 1981 survey size frequency distributions (Figure 27). Total catch per tow in Delmarva in 1981 was the lowest in the survey time series and was 76% lower than in 1980.

Abundance indices in Virginia-North Carolina have sequentially declined since 1978. Apart from modest recruitment from the 1975 year class reflected in both the 1978 pre-recruit index and shell height frequency distribution (Figure 28), no significant recruitment has ensuingly occurred. As a result, recruit and total abundance have progressively diminished. All of the 1981 Virginia-North Carolina indices (pre-recruit, recruit, and total numbers per tow) were among the lowest obtained in the survey series.

Overall, total catch per tow values for the entire Mid-Atlantic area declined 61% between 1975 and 1981 with the 1981 index (18.6) the lowest on record (Table 30). Commercial landings during 1976-1980 exceeded the total Mid-Atlantic landings taken during 1964-1975 (Table 7); New York Bight landings peaked at 4,656 tons in 1979, while Delmarva landings peaked in 1978 (5,567 tons) (Table 3). Since 1978, however, total annual fishing yields from the Mid-Atlantic resources have successively declined. Between 1978 and 1981, annual landings declined 76% while survey recruit indices declined by 66%. Commercial Mid-Atlantic CPUE was 62% lower in 1980 than in 1978 (Table 14). Together these data imply that current resource abundance throughout the Mid-Atlantic region is relatively low. The absence of strong recruitment in any of the Mid-Atlantic scallop regions suggests that the condition will continue to prevail during 1982.

USA spring and autumn bottom trawl survey indices of scallops in the Gulf of Maine indicate differential scallop abundance in waters between 30-60 fm and 61-100 fm (Table 31). In the 30-60 fm depth zone, total catch per tow indices since 1974 have been relatively stable (the 1977 autumn value appears to be anomalous). Survey size frequency distributions (Figure 29) imply that the 1974 and 1975 year classes were dominant in the population during 1978 and 1979, while the 1975 and 1976 cohorts dominated in 1980 and 1981. The 1981 survey shell height distribution also imply the existence of a 1978 year class (mode at 40 mm: see Table 20 for Gulf of Maine scallop size at age values). Most of the 1980-1981 offshore Gulf of Maine scallop exploitation is believed to have occurred in beds in the 30-60 fm depth range since the 1975 and 1976 year classes predominated in USA commercial samples obtained in these years (Figure 17).

Survey catch per tow indices in the Gulf of Maine 61-100 fm region were relatively low during 1974-1976 but markedly increased in 1977 (Table 31). Both spring and autumn size frequency distributions in 1977 and afterward (through 1980) imply that increases in abundance were due to a successful 1974 year class (Figure 30). Total catch indices peaked in the autumn 1980 survey at 35 scallops per tow, and at 98 scallops per tow in the spring 1981 survey. Although the autumn 1981 index declined 80% from the 1980 value (6.9 vs 34.9), this reduction probably reflects survey sampling variability since little, if any, commercial exploitation has occurred on these deep-water beds. Most scallop vessels fishing in the Gulf of Maine are not equipped with sufficient towing cable to effectively harvest scallops below 60 fathoms. Moreover, there is no indication of a decline in the average size of scallops in these deeper areas during 1980 and 1981, an effect normally observed with intensified fishing activity. In fact, the mean shell height of the survey samples has progressively increased, in both survey series, since 1979 (Table 31).

The 1981 spring pre-recruit index was the highest recorded (5.3) during the 1974-1981 sampling, suggestive of recent recruitment success. Inspection of the 1981 size frequency distribution reveals two modes: one at 70 mm implying above average recruitment of the 1976 year class, and a broader mode between 90-110 mm corresponding to the 1974 and 1975 year classes (Figure 30).

Although the long-term productivity of the 61-100 fm scallop populations is not known, the extremely high 1980-1981 survey indices (higher than those from any other Northwest Atlantic area except the Northern Edge and Peak) suggest that current scallop densities in this deepwater zone may be sufficient to support a commercial fishery at least in the short term.

Survey Variability

Precision of sea scallop survey indices (total standardized stratified mean number per tow) for all Georges Bank and Mid-Atlantic regions was assessed from estimates of the standard deviation of the mean and the associated coefficient of variation (ratio of standard deviation to the mean), on both a linear and ℓn (x+1) scale, calculated for each principal region in every survey year (Tables 32 and 33).

For the linear data, coefficients of variation range from 1.2 to 61.6% with most values higher on Georges Bank than in the Mid-Atlantic. The highest set of values occurred in the South Channel (29.4-61.6%), the consistently lowest in the New York Bight (8.7-19.5%). Annual values in almost all areas tended to fluctuate between 15 and 40%, with little apparent consistency between sample size (number of tows) and the resultant coefficient of variation (Table 27). No overt relationship between mean abundance and the coefficient of variation was detected, although in half of the regions the stratified mean and variance (standard deviation) were linearly related (Southern Part, Northern Edge and Peak and Delmarva: $P < 0.05$). The mean coefficients of variation for the overall Georges Bank and Mid-Atlantic stratified abundance indices (1975-1981) are 14.9% and 13.7%, respectively, implying that proportional changes in abundance of less than about ±30% will normally not be detected with high probability (i.e., $P = 0.05$). For individual regions, annual differences in total mean catch per tow less than ±30-60% would usually not be detectable given the higher level of variation associated with the separate areas.

The transformed (ℓn x+1) data exhibit much less variability than the linear values. Coefficients of variation range from 1.9 to 16.8% of the mean in all regions except for Virginia -North Carolina where, due to small sample sizes and inconsistent sampling of all strata within the strata set through time, the values are much higher. Equally, apart from Virginia-North Carolina, the variances (standard deviations) have been stabilized; none of the correlation coefficients between ℓn (x+1) mean catch per tow are significantly different from zero ($P>0.05$). Almost all of the transformed coefficients of variation are 1/3 to 1/2 as large as their respective linear values resulting in a significant improvement in relative precision using the ℓn scale. On an absolute basis, however, there is little improvement in detecting proportional changes in abundance since the retransformed confidence limits are about as large as the linear confidence bands (Tables 32 and 33).

Temporal trends in abundance as derived from the ℓn(x+1) and retransformed survey values are similar to the corresponding time series of fluctuations in the linear number per tow indices both within and among survey regions.

Sea Scallop Shell Height-Meat Weight Relationships

Sea scallop samples for shell height-meat weight analysis were collected from Georges Bank and Mid-Atlantic USA sea scallop research vessel surveys during 1977-1981. Offshore Gulf of Maine specimens were obtained in 1980 from commercial samples collected by the National Marine Fisheries Service, and the States of Maine and Massachusetts. Survey samples were randomly selected from the range of shell heights at a particular station; when catch permitted, a sample consisted of 30 adductor muscles (meats) with corresponding top valve shells per station. To insure broad geographical coverage, stations at which samples were to be collected were designated prior to the start of the survey. Gulf of Maine commercial samples were obtained from shell stock vessels fishing the Jeffreys Basin-Fippennies Ledge region, and represented random collections from the landed catch.

Shell height was recorded to the nearest millimeter, and the excised adductor muscle placed in an individual plastic bag and frozen. In the laboratory, the individual meat was weighed to the nearest 0.01 g.

Linear regression analyses were performed with height and weight data converted to natural logarithms with the form of the shell height-meat weight relationship assumed to be: $\ell n\ W = a+b\ \ell n\ H$. Meat weight-shell height equations were also computed; relationships were of the form: $\ell n\ H = a+b\ \ell n\ W$. Separate regression equations were derived for each principal scallop region sampled on Georges Bank and in the Mid-Atlantic, for aggregated Georges Bank and aggregated Mid-Atlantic samples, and for the Gulf of Maine. Regression and covariance analyses were conducted using procedures in Snedecor and Cochran (1967) and Neter and Wasserman (1974).

Statistical summaries of shell height and meat weight data are presented, by major area and sampling year, in Table 34. A total of 13,754 scallops were obtained from five survey cruises (3,036 from Georges Bank; 8,992 from the Mid-Atlantic) and eight commercial samples (1,726 from the Gulf of Maine). Survey samples were collected from 515 different sampling stations (136 stations on Georges Bank and 379 stations in the Mid-Atlantic); the 10-minute squares of latitude and longitude in which survey samples were acquired are depicted in Figure 31. Survey sampling coverage extended from Virginia-North Carolina to the Southeast Part of Georges Bank in depths from 29-106 m (16-58 fm).

Shell heights ranged from 23 to 169 mm, with average sizes, modal heights, and minimum and maximum values almost identical between the Georges Bank and Mid-Atlantic samples (Table 34; Figures 32 and 33). The mean height of Gulf of Maine scallops was slightly less than in the other regions and the height frequency distribution, spanning 36-123 mm, was nearly unimodal unlike the other distributions (Figure 34). The virtual absence of scallops less than 70 mm from the Gulf of Maine samples is a reflection of commercial dredge selectivity and culling practices.

Meat weights ranged from 0.08 to 117.73 g with the largest individual meats taken from the Mid-Atlantic. Average overall meat weight was similar on Georges Bank and in the Mid-Atlantic but was about 56% less in the Gulf of Maine (20.0 vs 8.8). The largest meat from the Gulf of Maine (24.4 g) was only 4.4 g greater than the average meat size in the Georges Bank and Mid-Atlantic samples.

Regression parameters and related statistics for the shell height-meat weight and meat weight-shell height relations are summarized, by area and year, in Tables 35 and 36, respectively. Covariance analyses between regression equations paired both within and among areas were all statistically significant ($P<0.05$). However, differences in predicted values among equations within areas were relatively minor and not considered meaningful (i.e., lacking external validity: Campbell and Stanley 1963). Accordingly, single equations were calculated for Georges Bank and the Mid-Atlantic areas pooling data from all years (Tables 35 and 36). Pairwise comparison of the three areal regressions (Georges Bank, Mid-Atlantic, and offshore Gulf of Maine) indicated that each was statistically different ($P < 0.05$) from one another, although no difference was detected between the slopes of the Georges Bank and Mid-Atlantic shell height-meat weight equations ($P > 0.10$) (Figure 35).

Calculated meat weights at various shell heights, using individual area shell height-meat weight regressions, reveal little differences between Georges Bank and the Mid-Atlantic; most values differ by less than 10% percent (Table 37). Similarly, offshore and inshore Gulf of Maine equations [the latter reported by Haynes (1966) and based upon Penobscot Bay samples] predict almost identical weight at height values over the 40-120 mm sample shell height range used in fitting the regressions. This correspondence implies that inshore and offshore Gulf of Maine scallops exhibit comparable allometric growth patterns. Gulf of Maine scallops, however, contain less meat per unit shell height than either Georges Bank or Mid-Atlantic scallops.

For a given meat weight (or meat count), predicted shell heights of scallops among geographical areas differ only slightly (Table 38). Between 20 and 60 meat count (7.56-22.68 g meat weight), the most extreme differences between calculated mean shell heights for scallops in any of the USA Northwest Atlantic regions are less than 13 percent. As meat weight increases, these percentage differences progressively decline.

Analyses of seasonal differences in shell height-meat weight regressions could not be performed with the present data since almost all of the survey samples were collected during summer cruises. Seasonal differences, however, have been reported in height-weight relations of Georges Bank scallops collected during October, November-March, and April-September (Haynes 1966) and related to gonadal maturation state. Accordingly, the relationships derived in the present study for use in basic fisheries analyses (meat count estimation and yield per recruit) may not have similar precision when applied for different purposes.

Relative Fecundity Relationships

Relative fecundity (weight of ovary to shell height; weight of ovary to meat weight: Bagenal 1973, 1978) for sea scallops from Georges Bank and the Mid-Atlantic was evaluated from ovary weight, meat weight, and shell height measurements obtained during the 1981 USA sea scallop research vessel survey conducted during 9-19 June (Mid-Atlantic) and 23-2 July (Georges Bank). Ovaries were excised from 1,770 individuals (647 from Georges Bank; 1,123 from the Mid-Atlantic) collected from 225 survey sampling stations (71 stations on Georges Bank; 154 stations in the Mid-Atlantic). Ten-minute square areas in which ovary samples were obtained are presented in Figure 36. Sampling was restricted to female scallops, 45 mm shell height and larger, exhibiting visibly distinguishable roe (i.e., reddish-colored gonad). Gonad samples were randomly selected from individuals representative of the height distribution at each station. After excision, the crystalline style was removed and the ovary placed in an individual plastic bag containing the sample number and shell height, and frozen. In the laboratory, the ovary (and corresponding adductor muscle sample) was weighed to the nearest 0.01 g.

Linear regressions of the form, $\ln O = a+b \ln H$ and $\ln O = a+b \ln W$, were fitted to the individual ovary weight, shell height, and meat weight data for each principal scallop region sampled (i.e., South Channel, New York Bight, etc.). Pooled regressions were also calculated for both the Georges Bank and Mid-Atlantic regions.

Data used in the relative fecundity analyses are summarized, by region, in Table 39. Average ovary weights were higher on Georges Bank than in Mid-Atlantic regions, although the mean shell heights and meat weights of samples in all areas were similar. The range in ovary weights was wider on Georges Bank (0.13-68.63g) than in the Mid-Atlantic (0.08-52.94 g); coefficients of variation, however, were of approximately the same magnitude. No consistent clinal trend in average ovary weight was observed among individual areas.

Regression statistics for the shell height-ovary weight and meat weight-ovary weight equations are presented in Tables 40 and 41, respectively. Correlation coefficients were relatively high and significantly greater than zero ($P<0.01$) except the Virginia-North Carolina values which were derived from only eight individuals. Analyses of covariance revealed no significant differences between any of the Mid-Atlantic regressions ($P>0.05$). South Channel and Southeast Part regressions were significantly different from each other and from any of the Mid-Atlantic regression lines ($P<0.05$). Pooled Georges Bank and Mid-Atlantic shell height-ovary weight equations (Table 40) differed in elevation (intercept values) but not in slope (Figure 37). The pooled meat weight-ovary weight relationships for these two areas, however, differed both in elevation and slope ($P<0.05$) (Figure 38).

Comparison of calculated mean ovary weights, among areas, over the shell height range used in the ovary weight-shell height analyses indicates that South Channel and Southeast Part scallops tend to have larger ovaries at a given shell size than scallops from the more southerly areas (Table 42). Assuming that the number of fully developed ova per gram of gonad is relatively constant, these data imply that Georges Bank scallops are more fecund per unit of shell height than those in the Mid-Atlantic. Over the 50-170 mm height range, calculated Georges Bank ovary weights are about 60% higher than Mid-Atlantic values, although much of this percentage difference results from the high relative fecundity of South Channel scallops.

At the size at which sea scallops become recruited to the commercial fishery (70 mm shell height), ovary weight is rather small ranging between 1-2 g in all areas. By the time scallops have attained 90 mm (approximately a year later: see Table 20), however, the ovary has doubled in size resulting in a significant increase in reproductive potential. In terms of meat size, ovary weight increases roughly 50% for both Georges Bank and Mid-Atlantic scallops during the half-year period of growth required for individuals to go from 60 to 40 meat count; between 40 and 30 count, ovary weight further increases by 35-40% (Table 43). Hence, substantial gains in potential egg deposition may be attained by increasing the size at which scallops are initially harvested in the commercial fishery. This will enhance reproductive potential by both elevating the number and fecundity of the spawning population, and increasing the number of eggs per recruit (Garrod and Knights 1979).

Yield Per Recruit

Yield per recruit analyses were performed for the Georges Bank, Mid-Atlantic, and offshore Gulf of Maine populations using the allometric model of Paulik and Gales (1964) since the slopes of the shell height-meat weight regressions for these areas (Table 35) were significantly greater than 3.0 ($P<0.001$). Calculations were conducted using the von Bertalanffy growth parameters presented in Table 20 with age at recruitment (t_p: age at first vulnerability to fishing gear) = 2.0 years and maximum age attained (t_λ) = 20 years. Natural mortality (M) was assumed to be 0.1 (Merrill and Posgay 1964). All analyses were accomplished by varying fishing mortality (F) between 0.01 and 1.50 and age at first capture (t_c) between 2.0 and 11.0 years (Tables 44-46). Transverse isopleths were also calculated for ages at first capture corresponding to 25, 30, 40, and 60 meat count scallops (Table 47; Figure 39).